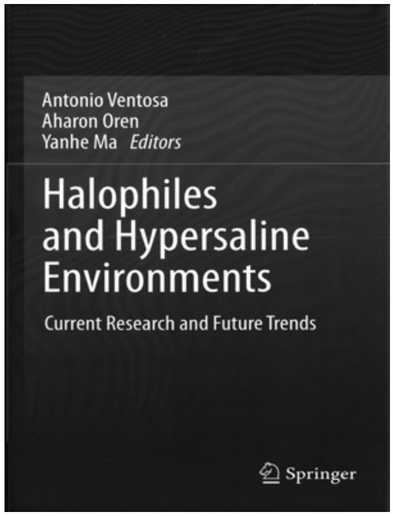


## Halophiles and hypersaline environments. Current research and future trends.

Antonio Ventosa, Aharon Oren, Yanhe Ma (eds)

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Although we often ignore their presence, colonies of halophiles can be readily recognized by the bright red color they confer on marine salterns and crystallizer ponds world-wide. They include populations of halophilic *Archaea* (Halobacteriales), *Bacteria* (*Salinibacter*), and *Eukarya* (*Dunaliella salina*) [p.173]. Salt (NaCl) has been generally considered hostile to most forms of life. Thus, for centuries, in addition to its use as a ubiquitous food seasoning, it has long been employed as a food preservative. However, halophilic and halotolerant microorganisms can contaminate salt-preserved food, consistent with their colonization of natural saline environments.

*Halophiles and hypersaline environments* originated at the international meeting "Halophiles 2010", held in Beijing, China, in July 2010. Edited by Antonio Ventosa (University of Sevilla), Aharon Oren (The Hebrew University of Jerusalem), and Yanhe Ma (Chinese Academy of Sciences), the book comprises 20 chapters whose authors, like the editors, are experts in the field. Three of these 20 chapters are devoted to historical aspects of halophiles research. Chapter 1 (coauthored by the editors) is a very moving text dedicated to the memory of Prof. Helge Larsen (1922–2005), one of the founders of halophilic microbiology and the greatest expert of his time on halophilic microorganisms. Chapter 2, by A. Oren, looks back on the history of microbiology, focusing on the work of Baas Becking (1895–1963), whose first studies on the salt lakes in California were done in the 1920s and laid the foundations for halophilic microbiology. Oren is also the author of the book's last chapter, a historical overview of the symposia on halophilic microorganisms, which started in 1978 in Rehovot, Israel. The remaining chapters of *Halophiles and hypersaline environments* inform the reader about the state of the art of the field of halophiles, thoroughly discussing the various lines of research.

Chapters 3–6 focus on the diversity that can be found in hypersaline environments, as evaluated by molecular (metagenomics, lipidomics) and culture-dependent methods. Several taxonomic aspects of certain halophilic microorganisms, including those in the Family Halomonaceae as well as *Salinibacter ruber*, a typical representative of the Bacteroidetes that shares many properties with Haloarchaea.

Baas Becking [see Quispel A. 1998. Lourens G.M. Baas Becking (1895–1963), inspirator for many microbiologists. *Int. Microbiol.* 1:69-72] was probably the first to realize that microorganisms living at high salt concentration could employ multiple survival strategies, and he focused his research on the adaptation of halopiles to life at extremes of salinity, pH, etc. Since then, there have been major studies of halophilic and halotolerant *Bacteria* and *Archaea*, as well as the eukaryotic alga *Dunaliella salina*, the only eukaryote able to adapt to these extreme conditions. Chapter 7 describes the molecular mechanism of adaptation to high salt concentration by the extremely halotolerant black yeast *Hortaea werneckii*. Halophilic and halotolerant fungi use polyols such as glycerol, erythritol, arabitol, and mannitol as osmotic solutes and retain low salt concentrations in their cytoplasm.

The first studies on organisms living in extreme environments date back to the late nineteenth century. However, it was not until the 1970s that viruses in halophilic environments were first described, and their role therein remains largely unexplored. Only recently has their participation in biogeochemical cycles and the genetic plasticity of their hosts been investigated. The morphology of viral particles in saturated brines has also been studied directly by electron microscopy of crystallizer samples, and new viral architectures have been found. It has become clear that NaCl-saturated brines are among the planktonic systems with the highest number of virus-like-particles (VLPs), ranging from $7.3\times10^7$ VLP/ml in crystallized ponds to $2\times10^9$ VLP/ml in the Dead Sea. The isolation and characterization of viruses that contain a lipid envelope surrounding either a single-stranded or double-stranded DNA genome has shown that viral diversity in hypersaline environments is much larger than previously assumed.

In salt lakes, haloviruses generally outnumber cells by 10- to 100-fold. The term halovirus refers to viruses that infect halophiles, the hosts being either bacterial or archaeal species. Phages have been obtained as pure cultures from haloarchaea for many years (*Halobacterium, Natrialba* sp., *Haloarcula* sp., *Haloferax* sp., and *Halorubrum* sp.) and some of them have been sequenced. Chapters 8 and 9 deal with the diversity of halophilic viruses in salterns and in the Great Salt Lake (Utah, USA), respectively.

Chapters 10–17 describe the physiology and molecular biology of halophiles, including different mechanism of translation, the glycosylation of proteins, protein insertion, and the transport of proteins across lipid membranes. Among the interesting physiological properties of halophiles is gas vesicle formation, by *Halobacterium salinarum*, and the nature and function of pigments such as carotenoids and xanthorhopopsin. The novel anaerobic halophilic alkali thermophiles are discussed as well. Halophiles exposed to multiple stressors have developed several unique adaptive mechanisms to control membrane permeability, intracellular osmotic balance, and the stability of the cell wall and intracellular proteins. Anaerobic halophilic, alkaliphilic, thermophilic bacteria have been isolated from the Wadi an-Natrun, in the Egyptian Sahara. Two new species, designated *Natranaerobius jonesii* and *Natranaerobius grantii*, are currently being characterized. The discovery of microorganisms capable of living in a combination of high salinity, pH, and temperature has extended our concept of the limits of life.

Thus far, halophiles have not been extensively exploited in biotechnological processes, with notable exceptions including the production of β-carotene by *Dunaliella*, bacteriorhodopsin by *Halobacterium*, and ectoine by *Halomonas.* However, as discussed in Chapters 18 and 19, because of their unique physiological traits halophilic microorganisms hold promise for other biotechnological applications. Their high stability at extreme conditions, such as high salt concentrations, low water availability, and high temperatures, make halophilic enzymes, including cellulases, lipases, amylases, and restriction enzymes, of particular interest in industrial and biotechnological applications, e.g., bioremediation and biofuel production.

The hypersaline environments of saltern pond brines and natural salt lakes have been traditionally overlooked by ecologists because they are considered to be relatively simple ecosystems with low diversity and high community densities. Nonetheless, they offer fascinating models to study fundamental questions of microbial biodiversity, selection, biogeography, and evolution. The book *Halophiles and hypersaline environments* provides an excellent overview of the current understanding of all aspects of the microbial world that lives in areas of high salt concentrations. Together with an earlier book on "salt-loving" microorganisms, *Halophilic microorganisms*, also edited by Antonio Ventosa (Springer, 2004; see review in *Int. Microbiol.* [2004] 7:233), this book provides a useful reference for researchers, students, and anyone interested in knowing more about these unique microorganisms.

**Ricardo Guerrero**
University of Barcelona
rguerrero@iec.cat